

Runoff and Sediment from Row-crop, Row-crop with Grass Strips, Pasture, and Forest Watersheds

Ruissellement et charges sédimentaires des bassins versants avec cultures en lignes, cultures en lignes avec bandes riveraines, pâturages et forêt

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Résumé de l'article

Les études comparant les volumes de ruissellement et les charges sédimentaires de bassins versants avec cultures en lignes et pâturages avec et sans zones tampons et bandes riveraines sont peu nombreuses. Les effets des précipitations, de l'occupation du sol et des conditions des zones tampons sur le ruissellement et les charges sédimentaires ont été analysés de 1997 à 1999 pour huit bassins versants comportant en proportions diverses des cultures en lignes, des pâturages, des zones tampons et des bandes riveraines. Il a été montré que les volumes de ruissellement et les charges sédimentaires pour les bassins versants avec cultures en lignes étaient inversement proportionnels aux pourcentages de forêt et de pâturages présents sur ces bassins. Les moyennes mesurées sur trois ans des volumes de ruissellement des bassins versants de type forestier, avec pâturages, avec cultures en lignes et avec cultures en lignes et bandes riveraines (RC-GFS) sont de 939, 1 560, 3 434 et 1 175 m³/ha/an respectivement. Les volumes de ruissellement mesurés pendant une année pour toutes les occupations du territoire ont été plus grands lorsque les précipitations ont été supérieures de 36 % à la normale (1998). L'événement générant le volume de ruissellement le plus important à survenir sur chaque bassin versant génère à lui seul de 11 % à 25 % du volume de ruissellement total mesuré. Les charges sédimentaires pour les bassins versants forestiers, avec pâturages, avec cultures en lignes et RC-GFS ont été respectivement de 1 017, 1 241, 3 679, et 2 129 kg/ha/an respectivement. En 1998, les charges sédimentaires des bassins versants RC-GFS ont été plus importantes que les bassins avec cultures en lignes alors que les volumes de ruissellement et les charges sédimentaires sur ces mêmes bassins ont été plus petits lors d'années avec des précipitations égales ou inférieures à la moyenne. Les bassins avec cultures en lignes et comportant 55 % de pâturages permettent une réduction de l'ordre de 55 % des volumes de ruissellement et de 66 % des charges sédimentaires lorsque comparés aux bassins avec cultures en lignes. Les charges sédimentaires mesurées à l'exutoire des bassins avec cultures en lignes ont été plus élevées pour 90 % des événements que celles issues des bassins avec pâturages ou forestiers. Les résultats de cette étude montrent que des bandes riveraines de 3 à 4 m, le maintien de plus de 55 % du territoire sous forme de pâturages/CRP pour des bassins avec cultures en lignes et la présence de bandes riveraines permettent de réduire de façon significative les volumes de ruissellement et les charges sédimentaires des bassins versants avec cultures en lignes.

RUNOFF AND SEDIMENT FROM ROW-CROP, ROW-CROP WITH GRASS STRIPS, PASTURE, AND FOREST WATERSHEDS

Ruissellement et charges sédimentaires des bassins versants avec cultures en lignes, cultures en lignes avec bandes riveraines, pâturages et forêt

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RÉSUMÉ

Les études comparant les volumes de ruissellement et les charges sédimentaires de bassins versants avec cultures en lignes et pâturages avec et sans zones tampons et bandes riveraines sont peu nombreuses. Les effets des précipitations, de l'occupation du sol et des conditions des zones tampons sur le ruissellement et les charges sédimentaires ont été analysés de 1997 à 1999 pour huit bassins versants comportant en proportions diverses des cultures en lignes, des pâturages, des zones tampons et des bandes riveraines. Il a été montré que les volumes de ruissellement et les charges sédimentaires pour les bassins versants avec cultures en lignes étaient inversement proportionnels aux pourcentages de forêt et de pâturages présents sur ces bassins. Les moyennes mesurées sur trois ans des volumes de ruissellement des bassins versants de type forestier, avec pâturages, avec cultures en lignes et avec cultures en lignes et bandes riveraines (RC-GFS) sont de 939, 1 560, 3 434 et 1 175 m³/ha/an respectivement. Les volumes de ruissellement mesurés pendant une année pour

toutes les occupations du territoire ont été plus grands lorsque les précipitations ont été supérieures de 36 % à la normale (1998). L'événement générant le volume de ruissellement le plus important à survenir sur chaque bassin versant génère à lui seul de 11 % à 25 % du volume de ruissellement total mesuré. Les charges sédimentaires pour les bassins versants forestiers, avec pâturages, avec cultures en lignes et RC-GFS ont été respectivement de 1 017, 1 241, 3 679, et 2 129 kg/ha/an respectivement. En 1998, les charges sédimentaires des bassins versants RC-GFS ont été plus importantes que les bassins avec cultures en lignes alors que les volumes de ruissellement et les charges sédimentaires sur ces mêmes bassins ont été plus petits lors d'années avec des précipitations égales ou inférieures à la moyenne. Les bassins avec cultures en lignes et comportant 55 % de pâturages permettent une réduction de l'ordre de 55 % des volumes de ruissellement et de 66 % des charges sédimentaires lorsque comparés aux bassins avec cultures en lignes. Les charges sédimentaires mesurées à l'exutoire des bassins avec cultures en lignes ont été plus élevées pour 90 % des événements que celles issues des bassins avec pâturages ou forestiers. Les résultats de cette étude montrent que des bandes

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riveraines de 3 à 4 m, le maintien de plus de 55 % du territoire sous forme de pâturages/CRP pour des bassins avec cultures en lignes et la présence de bandes riveraines permettent de réduire de façon significative les volumes de ruissellement et les charges sédimentaires des bassins versants avec cultures en lignes.

Mots clés : *Ruissellement, sédiment, cultures en lignes, forêt, bandes riveraines, CRP/pâturages*

ABSTRACT

Comparisons of runoff and sediment loss from row-crop with and without riparian buffers, pasture and grass filter strips are limited. Effects of precipitation, landuse and buffer condition on runoff and sediment loss were examined from 1997 to 1999 in eight watersheds with varying proportions of row-crop, pasture, riparian buffers and grass filter strips. Runoff volume and sediment mass from row-crop watersheds were inversely related to the percentage of forest and pasture cover. Forest ($n = 2$), pasture ($n = 3$), row-crop ($n = 2$) and a row-crop watershed with grass filter strips (RC-GFS) had 3-yr mean runoff of 939, 1,560, 3,434 and 1,175 $\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$, respectively. Runoff was greater from all landuses in a year when precipitation was 36% above normal (1998). The largest single runoff event from each watershed accounted for 11 to 25% of its total runoff. Forest, pasture, row-crop and RC-GFS watersheds lost 1,017, 1,241, 3,679 and 2,129 $\text{kg ha}^{-1} \text{yr}^{-1}$ of sediment, respectively. In 1998, the RC-GFS watershed lost more sediment than row-crop watersheds and had less runoff and sediment loss in years with normal or below normal precipitation. Row-crop watersheds with 55% pasture reduced runoff and sediment loss by 55 and 66%, respectively, compared to row-crop watersheds. During 90% of the runoff events, more soil was lost from row-crop watersheds than pasture or forest watersheds. Results suggest that 3–4 m grass filter strips, maintenance of 55% or more pasture/CRP land within row-crop watersheds and intact riparian buffers significantly reduce runoff and sediment losses from row-crop watersheds.

Key words: *Runoff, Sediment, Row-crop, Forest, Grass filter strips, CRP/pasture*

1. INTRODUCTION

Agricultural activities often impact the quality of surface and ground waters (CARPENTER *et al.*, 1998; USEPA, 1984). Suspended sediment in surface runoff is the most visible agriculturally derived non point source pollutant (NPSP)

(GINTING *et al.*, 1998), while excess nutrients are the single most important cause of impairment of lakes and the third most important cause of impairment for rivers and streams in the United States (USEPA, 2000). The main pathways by which agrochemicals, microbes and nutrients are removed from agricultural watersheds are runoff and suspended sediment losses (HARROD and THEURER, 2002; QUINTON *et al.*, 2001). Therefore, evaluation of runoff and sediment loss in watersheds is fundamental to the development of management strategies for sediment and sediment-bound nutrient losses (MATISOFF *et al.*, 2002).

Several studies have substantiated that riparian areas and grass filter strips are important for water quality preservation (COOPER and GILLIAM, 1987; DILLAHA *et al.*, 1989; GILLIAM, 1994; LOWRANCE *et al.*, 1984; PETERJOHN and CORRELL, 1984; SCHMITT *et al.*, 1999; WIGINGTON, *et al.*, 2003). Vegetative filter strips also are an effective best management practice for controlling sediment and sediment-bound nutrients with removal efficiencies ranging from 53 to 98% of sediment in runoff (DILLAHA *et al.*, 1989; ROBINSON *et al.*, 1996; SCHMITT *et al.*, 1999). Incorporation of pasture and hay in row-crop watersheds also reduces soil erosion (PRATO and WU, 1991). Sediment loss mainly occurs in surface runoff (ZHAO *et al.*, 2001), and therefore hydrologic pathways of water as it moves from agricultural fields to streams are a critical determinant of the effectiveness of buffers (WIGINGTON *et al.*, 2003). Riparian and grass buffer strips remove sediment from surface water by diffusing surface flow, increasing infiltration and trapping sediment (ROBINSON *et al.*, 1996). Physical, chemical and biological processes within a buffer, as well as soil, site and management practices influence the transport, transformation and retention of sediment. Studying more than 2,900 sites across the United States, SIMON *et al.* (2004) found sediment losses in runoff from agricultural land vary with ecoregion; highest suspended sediment loss occurred in humid regions with erodible soils on steep slopes or channel gradients.

Runoff and sediment loss are influenced by type of crop, season and tillage system. At the Claypan Experimental farm in Missouri, mean annual runoff and soil loss for soybean (*Glycine max* L. Merr.) were 3 and 12% higher than those for corn (*Zea mays* L.), respectively (GHIDEY and ALBERTS, 1998). This study found fallow-period soil loss was five times higher than the cropping period. In a soybean-sorghum rotational study in East-central Kansas, 3-yr average sediment losses on ridge-till and chisel-disk land preparations were 2- and 3-fold greater than no-till, respectively (JANSSEN *et al.*, 1996). Even agricultural watersheds under no- or minimum-tillage lose soil in runoff (CHUNG *et al.*, 1999).

Runoff volume and sediment loss vary widely during individual storm events, annual cycles and over time (CASSELL

et al., 1998; QUINTON *et al.*, 2001; RANDALL and MULLA, 2001; ROBINSON *et al.*, 1996). Soil loss generally parallels runoff, but intensity and amounts of individual rainfall events influence loss (JANSSEN *et al.*, 1996). EDWARDS and OWNENS (1991) observed the largest three erosional events caused more than 50% of the total soil loss, an observation supported by research in the UK (MORGAN *et al.*, 1986), USA (ROBINSON *et al.*, 1996) and Nigeria (LAL, 1976). In a 7-yr study of three adjacent watersheds in corn-soybean rotation, UDAWATTA *et al.* (2004) found the five largest runoff events and five largest sediment losses accounted for 27% and 24% of P loss, respectively.

States are required to implement water quality criteria, based on USEPA guidelines or other scientifically defensible methods (ICE and BINKLEY, 2003). Land owners, state agencies and other regulatory authorities need scientifically defensible, practically achievable and biologically relevant standards for proper development and successful implementation of water quality guidelines. Although riparian buffer strips, pasture land and grass filter strips seem advantageous to reduce NPSP from agricultural watersheds, from economic and practical perspectives, experimental studies comparing effectiveness of these managements by ecoregion or landuse are largely missing from the literature. This paper examines (1) the effects of landuse, pasture and row-crops with and without grass filter

Table 1 Summary of forest, pasture and row-crop cover percentages and area of eight watersheds.

Tableau 1 Occupation du territoire pour les huit sous-bassins à l'étude.

Watershed	Area -- ha --	Cover distribution		
		Forest	Pasture	Row-crop
		----- % -----		
Forest				
100	65	84	2	12
101	87	94	0	4
Pasture				
200	70	28	66	6
201	30	43	57	0
202	26	18	41	41
Row-crop				
300	140	7	7	86
301	259	4	22	75
RC-GFS (400)	21	0	0	100

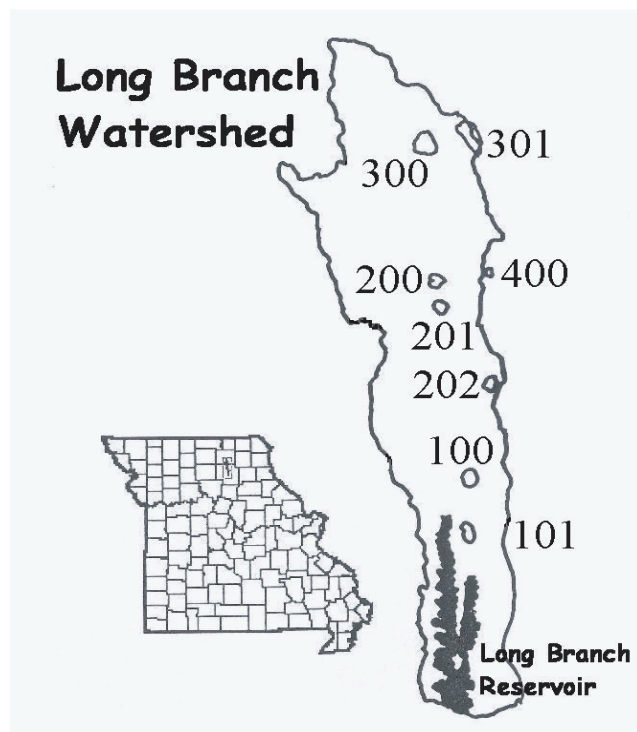


Figure 1 Long Branch Watershed and Reservoir in Macon and Adair Counties, Missouri, USA and approximate location of eight watersheds within the Long Branch Watershed.

Bassin versant et réservoir Long Branch dans les comtés Macon et Adair, Missouri, États-Unis et localisation approximative des huit bassins sous étude dans le bassin versant Long Branch.

strips on discharge of water and sediment and (2) the effects of precipitation distribution on runoff and sediment loss.

2. MATERIALS AND METHODS

2.1 Study Area and Watershed Characteristics

Watersheds located within the Long Branch Watershed in Macon and Adair Counties (39° 50' N to 40° 05' N and 90° 32' W to 92° 20' W), Missouri, USA, were studied during 1997-1999 (Figure 1). Three land management types were included: at one extreme, forest catchments ($n = 2$), and at the other extreme, row-crop ($n = 3$) catchments with virtually no riparian vegetation, and pasture/Conservation Reserve Program (CRP) catchments ($n = 3$) as the intermediate condition. The two forest catchments were within the state-owned Atlanta Conservation Area.

Study watersheds ranged in area from 21 to 259 ha, and landuse within each watershed is summarized in table 1. Areal land use patterns were measured from 1:24,000 areal photographs (provided by Adair and Macon County, USDA Service Stations). Landuse classification was verified by observations during the study. Watersheds were identified

based on major land management type: forest (1xx), pasture (2xx), and row-crop (3xx). Within each land management category, the northern-most watershed was assigned the smallest number and *vice versa* (Figure 1). One row-crop watershed (400) received irrigation water from the La Plata Water Treatment Plant. Watershed 400 does not have a forested riparian buffer zone but has a 3 to 4 m wide dense grass filter strip along the stream. Therefore, this watershed was classified as a row-crop watershed with a grass filter strip (RC-GFS). These watersheds had low human population with no sewage outfalls. Cattle were present during certain periods in summer in watershed 202.

Pre-settlement vegetation was dominated by forests and tall, native grass prairies well-adapted to climate and soils of the area (FERGUSON, 1995; STEYERMARK, 1996). The dominant trees in forest tracts and riparian areas were white oak (*Quercus alba* L.), black oak (*Q. velutina* Lam.), post oak (*Q. Stellata* Wangenh.), pin oak (*Q. Palustris* Muenchh.), hickory (*Carya spp.*), elm (*Ulmus spp.*), osage orange (*Maclora pomifera*) and cedar (*Juniperus virginiana*).

Agricultural watersheds were in a corn (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.) rotation under minimum- or no-till cultivation. Wheat and sorghum represented little land cover in row-crop watersheds. Pasture/CRP watersheds were mainly under CRP. Fescue (*Festuca spp.*), golden rod (*Solidago spp.*) and cool season grasses were common in pasture watersheds. Row-crop and pasture watersheds contained varying degrees of forest riparian buffer (Table 1).

Soils in the region are developed from glacial till, loess, and pedisegment (FERGUSON, 1995). The surface was created by glaciation. Some soils are formed from loess and underlying pedisegment (UNKLESBAY and VINEYARD, 1992). The landscape is characterized by gently to strongly sloping uplands.

The average snowfall in the study area is about 61 cm and generally lasts several weeks. The average winter temperature is -2.2°C and average daily minimum is -7.7°C. In summer, the average temperature is 23.9°C and average daily maximum is 30°C. The 30-yr precipitation averages 967 mm, about 65% of which falls in April through September (OWENBY and EZELL, 1992).

2.2 Sample Collection and Analysis

ISCO samplers and flow measuring devices (Lincoln, NE, USA) were installed annually in late February or during the first week of March (1997, 1998, and 1999) to record flow rate, water level, sampling time and collect water samples. Thus, the sample collection period extended from March to

December each year. Generally, streams were frozen during winter, and little or no stream flow occurred.

All eight streams were surveyed and stream characteristics were fitted to Manning's equation to estimate water flow from rating curves of flow *versus* depth. Flow measuring devices controlled the sampler to collect water samples. Samples were collected at 30-minute intervals from the rising limb of the hydrograph and at 90-minute intervals from the falling limb of the hydrograph. During 1999, samples were collected based on pacing volume, such that after a set amount of water flow, the flow meter would signal sample collection. Because runoff varies with watershed size, landuse patterns and season, pacing volumes were larger for large row-crop watersheds (300: 1,400 m³ and 301: 4,000 m³) compared to the small row-crop (400: 200 m³), pasture (200: 300 m³ and 202: 200 m³), and forest (100: 600 m³) watersheds. Samples were delivered to collection bottles through vinyl suction tubes that were first rinsed with stream water. Sample inlets were positioned in the middle of the stream.

During some weeks, flow was either too low to generate an automatic sample or the sampler failed. If a sampler malfunction was detected, the sampler was replaced as soon as possible. Samplers on watersheds 100 (22-6-97 and 12-3-98) and 201 (18-5-97) failed due to sand blocking the suction line. The sampler and flow meter on watershed 301 was damaged twice (18-9-97 and 29-6-98) by lightning. The sampler housing for watershed 300 was placed on a four-foot shelf, but stream flow inundated the stream bank area several times during the study period. After a runoff event, flow, level and sample intake time data were downloaded from recorders. Water samples were transferred from the field to the laboratory and individual samples were analyzed for all the parameters of interest during the first two years of the study. During the third year (1999), composite samples from each runoff event were analyzed.

A known volume of well mixed sample was filtered through a pre-weighed glass microfiber filter (934-AH) using a vacuum pump (maximum vacuum 7 lbs in -2 above ambient) to estimate sediment weight. These filters were dried at 105°C to a constant weight and dry weight was recorded. Differences between the tare weight and sample volume were used to estimate the weight of total suspended sediment. Samples were refrigerated at 4°C until analysis.

2.3 Statistical Analysis

Statistical analysis of data was performed using SAS (SAS INSTITUTE, 1999). Normal distributions of runoff and sediment losses were tested using Shapiro-Wilk and Kolmogorov-Smirnov tests and log transformed data were used for further analysis. Random variables were analyzed as

a split-plot intime using the procmixed procedure in SAS. The main plot consisted of land management (treatments) and the subplot consisted of year and interaction of land management*year. Watersheds within a treatment were used as the denominator of F for the main plot (land management) effect. Watersheds within a land management and year was used as the denominator of F for the sub-plot (year and interaction of land management*year) effects. The residual mean square represented multiple observations within a year watershed combination. The fixed effects are land management, year and the interaction of land management*year. Mean differences were determined using Fisher Least Significance (LSD) and were calculated using Lsmeans statement within the Procmixed procedure. The variance covariance matrix was investigated using AIC coefficient to determine the most suitable mean separation procedure.

3. RESULTS

3.1 Precipitation and Stream Flow

Long Branch (LB) and Kirksville Radio Station (KRS) weather stations received 21% and 13% less precipitation in 1999 (March to August) compared to the 30-yr average, respectively (Figure 2). These two stations also received 18.5% and 10% less in 1997. Whereas during 1998, the region received 36% (LB: 43 and KRS: 30%) more rain compared to the 30-yr average.

The study area received rain on 62 dates ranging from a trace to 43 mm in 1999. No measurable runoff events occurred after 17 May, 1999. During the 1997 sampling

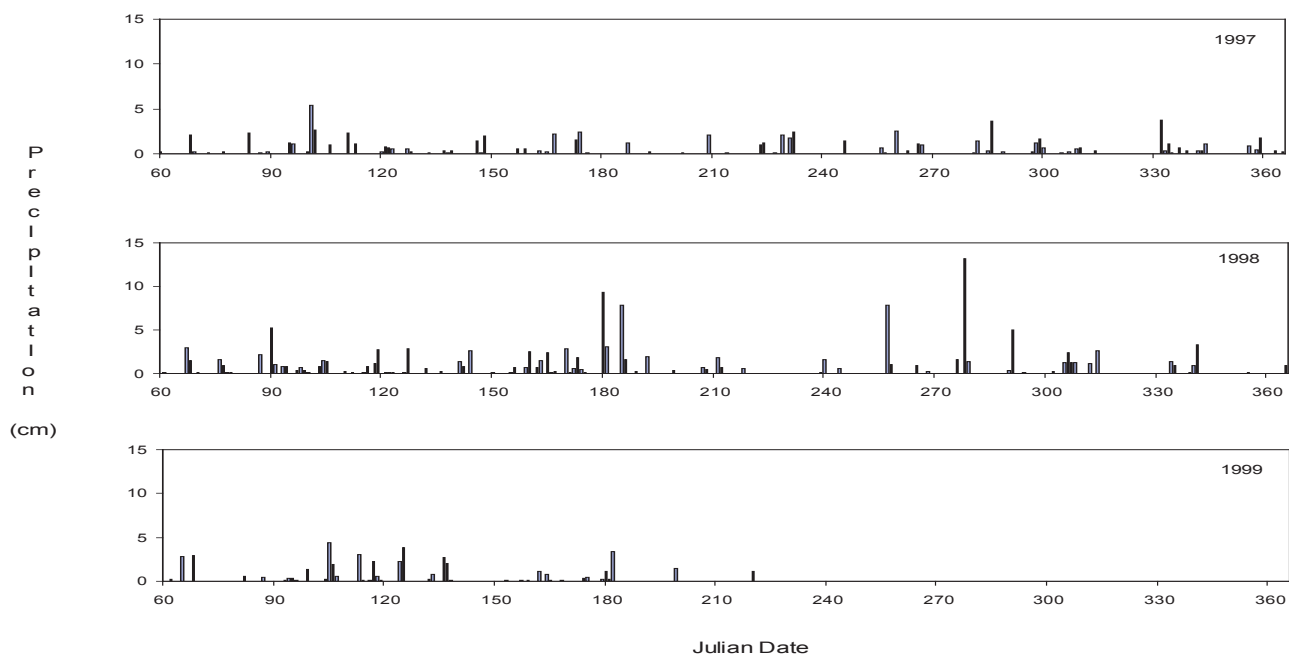


Figure 2 Precipitation distribution for the study area from Long Branch Weather Station during 1997-1999 (July and August 1999 data were not available).

Distribution des précipitations pour le territoire à l'étude de la station météorologique Long Branch durant la période 1997-1999 (les données de juillet et août 1999 n'étaient pas disponibles).

Table 2 Measurable runoff events during 1997-1999 for eight watersheds.

Tableau 2 Événements de ruissellement mesurables pendant la période 1997-1999 pour les huit bassins sous étude.

Year	Watershed							
	100	101	200	201	202	300	301	400
1997	6	2	9	8	10	14	21	16
1998	16	13	17	19	16	18	20	22
1999	8	†	7	†	8	10	9	8
Total	30	15	33	27	34	42	50	46

† Not sampled in 1999

period, rain occurred on 136 dates, ranging from a trace to a maximum of 54 mm. Rainfall events generating runoff ranged from 2.5 to 54 mm in study watersheds. Rain ranging from a trace to 132 mm was recorded in 1998 and 22 storm events on average produced more than 13 mm of precipitation. Rainfall generating runoff ranged from 9 to 128 in the watersheds.

Measurable runoff events from watersheds generally followed precipitation (Table 2). During sampling in 1999, forest watershed 100, the pasture and the row-crop watersheds produced 8, 7 and 9 runoff events, respectively. In 1997, the two forest watersheds, on average, produced four measurable flows (100: 6 and 101: 2). Pasture and row-crop catchments recorded 9 and 17 runoff events in 1997, respectively. Sampling year 1998 resulted in 14, 17 and 20 measurable runoff events from forest, pasture, and row-crop land uses, respectively.

3.2 Runoff Volume

The 3-yr mean annual discharge of water per area differed greatly among watersheds, ranging from 563 m³ ha⁻¹ yr⁻¹ (200) to 3771 m³ ha⁻¹ yr⁻¹ (301; Table 3). The 3-yr mean runoff volumes from forest, pasture, row-crop and RC-GFS land management types were 939, 1,560, 3,434 and 1,175 m³ ha⁻¹ yr⁻¹, respectively (Figure 3). The 3-yr mean annual runoff for the row-crop land management was 3.7, 2.2 and 2.9 times larger than that of forest, pasture and RC-GFS types, respectively. However, runoff volumes between the row-

crop and RC-GFS watersheds were not significantly different ($p \leq 0.08$). Pasture and RC-GFS watersheds produced 1.7 and 1.3 times more runoff than forest watersheds, respectively.

3.3 Large Runoff Events

Discharge varied with rainfall, and maximum runoff from the study watersheds occurred on different dates. Watersheds 100 (375 m³ ha⁻¹), 200 (237 m³ ha⁻¹), 201 (361 m³ ha⁻¹) and 400 (394 m³ ha⁻¹) had maximum runoff on 4 July, 1998 (Figure 4). Runoff events on 30 March, 1998 caused maximum runoff on watersheds 300 (1,121 m³ ha⁻¹) and 202 (333 m³ ha⁻¹), respectively. Watersheds 101 (462 m³ ha⁻¹) and 301 (1,111 m³ ha⁻¹) had maximum runoff on 14 March, 1998 and 14 April, 1999, respectively. Due to lightning damage, runoff data were not available for watershed 301 on 4 July, 1998 which was probably the largest event during the study.

The largest single runoff event in each land management category accounted for 20%, 12%, 25% and 11% of the total runoff in forest, pasture, row-crop and RC-GFS watersheds, respectively (Table 4). The proportion of total runoff contributed by the largest runoff event varied among watersheds. Largest events from forest watersheds 100 and 101 accounted for 13% and 27% of the total discharge, respectively. Differences among watersheds within a given land use type were larger between the two forest watersheds than the other categories. The largest runoff events from the

Table 3 Mean and annual runoff volumes during the three-year study period for four landuse types and for eight watersheds.

Tableau 3 Moyennes et volumes annuels de ruissellement pour les trois années d'étude selon les quatre types d'occupation du territoire et les huit bassins.

Watershed	Mean	Year		
		1997	1998	1999
----- m ³ ha ⁻¹ yr ⁻¹ -----				
Forest				
100	1022	538	1725	803
101	857	241	1473	†
Mean	939	389	1599	803
Pasture				
200	563	294	1175	220
201	3022	738	5307	†
202	1096	745	1714	831
Mean	1560	592	2732	525
Row-crop				
300	3098	1490	5495	2310
301	3771	1924	5631	3759
Mean	3434	1707	5563	3034
RC-GFS	1175	1134	1967	517

† Not sampled

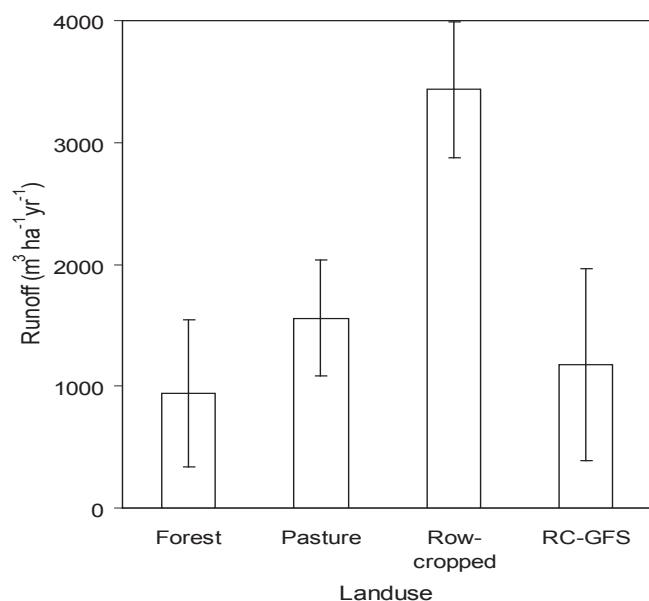


Figure 3 Mean runoff for forest, pasture, row-crop and row-crop-grass filter strip watersheds.

Ruissellement moyen pour les bassins forestiers, avec pâturages, avec cultures en lignes et avec cultures en lignes et bandes riveraines.

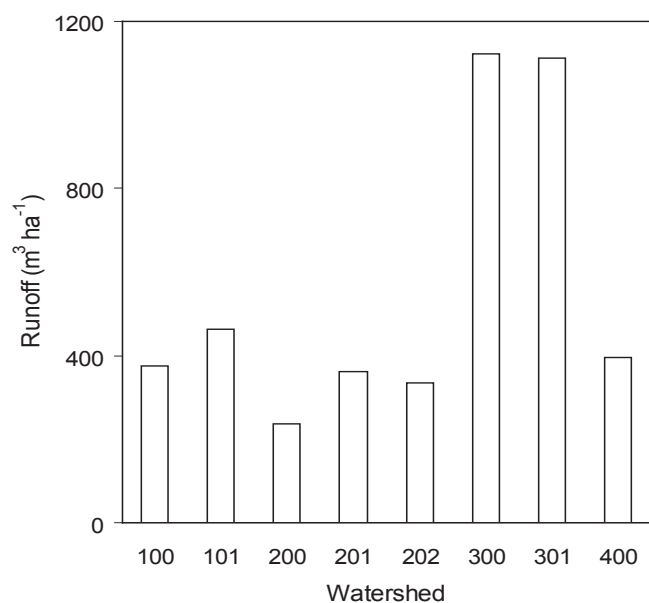


Figure 4 The maximum runoff volumes on the eight watersheds during the three-year study.

Volume de ruissellement maximum pour les huit bassins sous étude pendant la période de trois ans.

Table 4 Cumulative percentage of total runoff from the three largest runoff events during the three-year study period for eight watersheds and four landuse types.

Tableau 4 Pourcentage cumulatif du volume de ruissellement pour les trois événements les plus importants à survenir sur la période d'étude pour les huit bassins et les quatre occupations du territoire.

Watershed	Storm rank		
	1	2	3
	----- % -----		
Forest			
100	13	24	33
101	27	43	57
Mean	20	33	45
Pasture			
200	14	22	29
201	13	21	28
202	10	19	27
Mean	12	21	28
Row-crop			
300	26	36	42
301	24	31	38
Mean	25	33	40
RC-GFS	11	18	25

Table 5 Mean and annual soil loss during the three-year study period for four landuse types and for eight watersheds.

Tableau 5 Moyennes et charges sédimentaires annuelles pour la période d'étude pour les quatre occupations du territoire et les huit bassins sous étude.

Watershed	Mean	Year		
		1997	1998	1999
		----- kg ha⁻¹ yr⁻¹ -----		
Forest				
100	1247	784	1428	1529
101	788	273	1304	†
Mean	1017	528	1366	1529
Pasture				
200	1237	1380	2122	211
201	1748	544	2952	†
202	738	151	1416	649
Mean	1241	691	2163	430
Row-crop				
300	3777	3498	3499	4335
301	3581	2304	3585	4856
Mean	3679	2901	3542	4595
RC-GFS	2129	428	4082	1877

† Not sampled

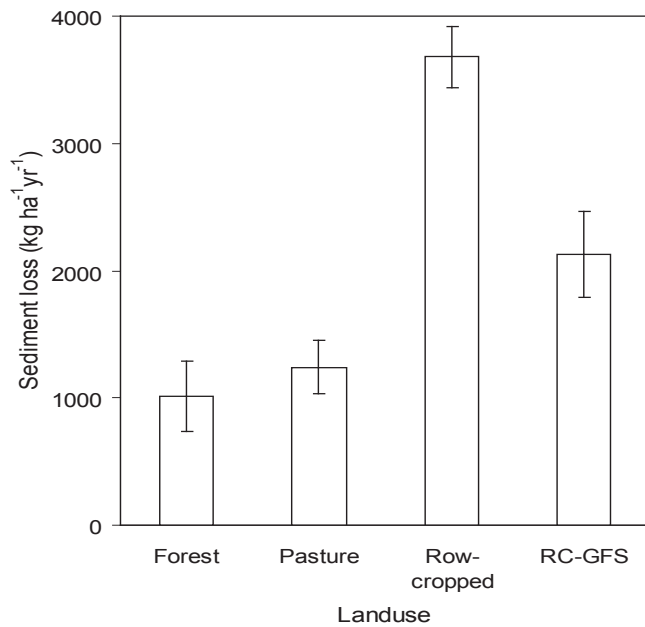


Figure 5 Mean sediment loss from forest, pasture, row-crop and row-crop-grass filter strip watersheds.
Charges sédimentaires moyennes pour les bassins forestiers, avec pâturages, avec cultures en lignes et avec cultures en lignes et bandes riveraines.

pasture watersheds accounted for 10-14% of the total, and in row-crop, the value was 24-26%.

3.4 Total Suspended Sediment Loss (TSS)

Three-yr mean soil erosion values from the eight watersheds ranged between 738 (202) and 3,777 (300) kg ha⁻¹ yr⁻¹ (Table 5). The 3-yr mean soil erosion on forest, pasture, row-crop and RC-GFS were 1,017, 1,241, 3,679 and 2,129 kg ha⁻¹ yr⁻¹, respectively, (Figure 5). Row-crop watersheds lost 3.6 and 2.9 times more soil compared to forest and pasture watersheds, respectively. Row-crop watershed with grass filter strip (400) and pasture watersheds lost only 58 and 34% soil, respectively, compared with row-crop watersheds (Figure 4).

Row-crop watersheds lost 2,901 kg TSS ha⁻¹ yr⁻¹ in 1997 (Table 5). Soil loss from row-crop watersheds in 1997 was 5.5, 4.2 and 6.8 times greater than forest, pasture and RC-GFS land managements, respectively. Soil erosion in 1997 and 1999 on the RC-GFS was only 15% and 41% of that on two row-crop watersheds (Table 5). Most storm events occurred early in 1999 and caused severe erosion when the ground was bare and before the soil lost its recharge. The two row-crop watersheds had more erosion in 1999 than in 1997 or 1998.

Table 6 Cumulative percentage of total erosion from the three largest runoff events during the three-year study period for eight watersheds and four landuse types.

Tableau 6 Pourcentage cumulatif de la charge sédimentaire pour les trois événements les plus importants à survenir durant la période considérée pour les huit bassins et les quatre occupations du territoire sous étude.

Watershed	Storm rank		
	1	2	3
	----- % -----		
Forest			
100	15	28	38
101	28	56	68
Mean	21	42	53
Pasture			
200	22	35	47
201	16	27	38
202	24	38	50
Mean	21	33	45
Row-crop			
300	33	53	63
301	24	39	47
Mean	28	46	55
RC-GFS	23	36	42

3.5 Sediment Loss During Large Storm Events

The largest single runoff event accounted for 21% to 28% of total soil loss among the various land management categories during the 3-yr study (Table 6). The percentage of soil loss caused by the largest single event among watersheds varied between 15% and 33% in this study. Averaged over eight watersheds, the single biggest runoff event accounted for 23% of the total soil loss measured during the study period. The largest three runoff events accounted for over half of the total erosion from forest and row-crop watersheds. Pasture and RC-GFS watersheds lost 45% and 42% of the total loss during the largest three events. The largest two and three episodes caused 39% and 49% of the total soil loss from all eight watersheds during the 3-yr study period.

3.6 Erosion on Forest and Pasture, versus Row-crop Watersheds

The 2-yr mean erosion values for the forest and pasture watersheds were 947 and 1,427 kg ha⁻¹ yr⁻¹, respectively (Table 7). Using the 2-yr mean erosion amounts on forest and pasture land managements as base values, we compared erosion on the row-crop watersheds (300 and 301) and the RC-GFS (400) watershed to quantify the proportion of events on row-crop and RC-GFS watersheds that generated erosion

Table 7 Number of runoff events as a percentage of total events on the three row-crop watersheds with soil erosion less than the mean soil erosion on forest ($947 \text{ kg ha}^{-1} \text{ yr}^{-1}$) and pasture ($1427 \text{ kg ha}^{-1} \text{ yr}^{-1}$) landuse types for individual years and for the three years of the study.

Tableau 7 Nombre d'événements et pourcentage du nombre total d'événements de ruissellement pour les trois bassins avec culture en lignes dont l'érosion a été moindre que celle mesurée sur les occupations de territoire de types forestier (947 kg/ha/an), et avec pâturages ($1\,427 \text{ kg/ha/an}$) pour chacune des années d'étude.

Watershed	Forest				Pasture			
	1997	1998	1999	3-yr	1997	1998	1999	3-yr
	----- % -----				----- % -----			
300	14	5.5	0	9.5	21	5.5	0	9.5
301	14	15	0	12	24	15	0	16
400	25	4.5	0	10.9	31	9	0	15

equal to or less than the 2-yr mean erosion from forest and pasture watersheds.

None of the events in 1999 had erosion amounts similar to that from forest or pasture watersheds (Table 7). The above normal precipitation in the previous year and early season runoff in 1999 caused severe erosion on all row-crop watersheds even though the study area received below average precipitation. In 1997, 14% and 25% of erosion events on row-crop and RC-GFS watersheds had erosion amounts similar to forest watersheds. In 1998, relatively few erosion events on row-crop watersheds generated erosion amounts that were similar to or less than those of forest and pasture watersheds. During the 3-yr study, watersheds 300, 301 and 400, had 10, 12 and 11% of erosion events that were similar or less than the erosion on forest watersheds, respectively (Table 7). Approximately 90% of erosion events from row-crop watersheds exceeded the mean erosion on forest and pasture watersheds.

4. DISCUSSION

4.1 Effects of Precipitation, Watersheds and Sampling

Annual, seasonal and within growing season variation in the frequency and intensity of precipitation influenced runoff. The study region received 16% less precipitation than the 30-yr average in 1997 and 1999, and runoff from all watersheds was lower compared to runoff on 1998 regardless of land cover type (Table 3). Annual rainfall during 1998 at each weather station was about 36% greater than the 30-yr average. Consequently, runoff volumes were also above long-term averages for the area and most watersheds had the largest runoff. This observation is supported by a 10-yr study with three adjacent corn-soybean rotational watersheds in northeast Missouri, where 27 or more runoff events occurred when precipitation was above 40% and fewer events when precipitation was normal or below normal (UDAWATTA *et al.*, 2002).

We also assumed that watershed boundaries coincided with topographically defined catchment of the surface runoff. All of our agricultural watersheds varied by less than 2 m elevation, and therefore, boundary demarcations and the true watershed area may be inexact. Surface runoff and ground water can cross topographically defined boundaries, so the collection area of the stream becomes uncertain (GARRISON *et al.*, 1987). ISCO submerged probes measure and collection strainers collect when flow was greater than 2.5 cm. Runoff occurred due to low level flow events could also account for the slightly larger annual total discharges from these watersheds. Hydrologic variability among watersheds also may have resulted in a wide range of runoff volumes within a land use category (EDWARDS and OWENS, 1991; LOWRANCE *et al.*, 1985; PETERJOHN and CORRELL, 1984; QUINTON *et al.*, 2001; UDAWATTA *et al.*, 2002; 2004; ZHENG *et al.*, 2004). Differences in discharge can also be due to erosional stage of the watershed and vegetation condition.

4.2 Effect of Landuse

In spite of differences in precipitation and soils among watersheds, the general effects of landuse on runoff and sediment loss were evident. Overall, forest watersheds did not have as many runoff events compared to pasture or row-crop watersheds. Forest watersheds had 18% and 72% less sediment loss than pasture and row-crop landuse. Literature supports that forest watersheds in general have less runoff and sediment loss (LOWRANCE *et al.*, 1985). The two watersheds are located in the Atlanta Conservation Area and are > 85% forest. Forest vegetation reduces runoff, soil erosion and nutrient loss from watersheds and improves infiltration and water holding capacity of soils (LOWRANCE *et al.*, 1985; GILLIAM, 1994). In contrast, row-crop watersheds had the largest discharges of runoff ($3,434 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$) and sediment ($3,679 \text{ kg ha}^{-1} \text{ yr}^{-1}$). These two watersheds had degraded riparian buffers with sparsely distributed understory growth. The riparian corridor on watershed 300 has poorly drained soils and most of the time soils remained wet. The other row-crop watershed (301)

has a small buffer strip along the stream and its stream incision is deep. Watersheds with less homogeneous soils, surface slopes, management and non-uniform buffers may result in short circuiting of surface runoff where runoff flows preferentially through only parts of the buffer strip.

Research shows that grass strips reduce runoff and sediment losses ranging from 30-90% and 60-90%, respectively (PATTY *et al.*, 1997; ROBINSON *et al.*, 1996; SCHMITT *et al.*, 1999). Discharge from the RC-GFS watershed was 34%, 64% and 83% less than that from row-crop watersheds in 1997, 1998 and 1999, respectively. The grass filter strip along the stream was 3-4 m wide and may have utilized water in spring and early summer, thus runoff and erosion losses were less than that of row-crop watersheds. During 1997 and 1999, the study area received 16% less precipitation than the 30-yr mean and the grass filter strip on the RC-GFS watershed reduced soil erosion by 85 and 60% relative to the other two row-crop watersheds, respectively. Most of the sediment reduction occurs within the first 7.5 m width of the strip (SCHMITT *et al.*, 1999). In 1998, the RC-GFS watershed lost 15% more soil than row-crop watersheds. During above normal precipitation in 1998, the width of the filter strip may have been insufficient to control erosion because transpiration loss of the permanent vegetation and infiltration capacity of the soil may have been exceeded by runoff and antecedent water content. The results showed that grass filter strips provide a way to improve surface water quality in agricultural watersheds, and they are more effective in years with normal precipitation distributions and under low flow conditions.

CRP/Pasture watersheds had 65%, 50% and 83% less runoff in 1997, 1998 and 1999 than row-crop watersheds and reduced sediment loss by 55% relative to row-crop land management. These watersheds, on average, contained 30% and 55% forest and pasture covers, respectively (Table 1). CRP/pasture has been shown to increase soil structure due to the presence of live and dead roots, fungal hyphae and other organic material than do annual vegetation and thereby reduce runoff and sediment loss (WIENHOLD and TANAKA, 2000; ZHENG *et al.*, 2004). DARVIE and LANT (1994) stated that conversion of row-crop areas in Illinois to CRP would reduce erosion by 30%. Row-crop watersheds with CRP/pasture in this study showed greater reductions in sediment loss than the CRP lands in Illinois. Within a watershed, CRP/pasture lands were located between the crop and forest areas and this could have improved sediment reduction in runoff. Many authors have shown the merits of a naturally vegetated riparian zone in improving water quality (GILLIAM, 1994; LOWRANCE *et al.*, 1985).

Control of fallow period and bare ground soil loss was important to reduce NPSP from row-crop watersheds (GHIDEY and ALBERTS, 1998; UDAWATTA *et al.*, 2004).

Until crops establish a good ground cover, soils are susceptible to raindrop impact and erosion compared to the pasture areas. Studying soil erosion on corn, wheat and meadow watersheds, EDWARDS and OWENS (1991) observed that 92% of the soil loss occurred in corn fields, 8% in wheat fields and no erosion in grass-meadow fields. It is unlikely that row-crop watersheds reduce soil and nutrients losses in runoff during the fallow period compared to the cropping period (UDAWATTA *et al.*, 2004). A comparison of soil losses in 1999 from RC-GFS and CRP/pasture *versus* row-crop watersheds proves that cool season grasses that cover the soil reduce soil loss early in the season and plant material and roots enhance settling of sediment. Results indicate that CRP/pasture land within a row-crop watershed improves water quality compared to a watershed with no CRP/pasture. The expected reduction in sediment loads through the conversion depends on time, watershed size, landuse, channel morphology and precipitation characteristics.

Large runoff events were responsible for removing substantial amounts of sediment and nutrients from row-crop watersheds (LAL, 1976; MORGAN *et al.*, 1986; QUINTON *et al.*, 2001; ROBINSON *et al.*, 1996; UDAWATTA *et al.*, 2004). In this study, the three largest runoff events accounted for approximately half of the total erosion. In a 28-yr study in Coshocton, Ohio, with more than 4,000 rainfall events, more than 66% of the soil loss occurred in large five events (EDWARDS and OWENS, 1991). However, erosion producing large events accounted for differing amounts of the total erosion among watersheds within a given land use. For example, during the largest two and three erosional events, watersheds 301 and 300 lost 39% to 53% and 47% to 63%, respectively of the total soil eroded. Differences in erosion among watersheds within the same management demonstrate the importance of large storms on total erosion and long-term evaluation to determine best management practices. On the other hand, smaller events that occur more frequently may account for a greater proportion of total nutrient loss than infrequent large events (QUINTON *et al.*, 2001; UDAWATTA *et al.*, 2004). These require less energy to detach soil particles (QUINTON *et al.*, 2001). In contrast, large events have more energy to remove nutrient-rich surface as well as nutrient-poor subsurface soils. In order to control NPSP in runoff, nutrient and sediment losses from all events need to be reduced.

5. CONCLUSIONS

Grass filter strips, CRP/pasture and riparian buffers reduced runoff volume (66%, 54% and 73%, respectively) and sediment loss (42%, 66% and 72%, respectively) from row-crop agriculture. Results indicate that varying proportions of forest, pasture and row-crop cover structure affect both runoff and sediment loss in a catchment with typical Midwestern U.S. corn-soybean rotation. Year to year variation in precipitation

significantly influenced runoff volume and sediment loss irrespective of landuse. The smallest runoff and sediment losses were from forest watersheds and the largest losses were from row-crop watersheds. The watershed with a grass filter strip and CRP/pasture watersheds had intermediate runoff and sediment losses. Although permanent vegetation reduced NPSP from row-crop agriculture, reduction amounts varied among watersheds within a landuse. This shows the importance of specific management strategies for individual watersheds that depend on location of crops and permanent vegetation within a watershed.

Results of this study suggest that more emphasis should be placed on management strategies that minimize runoff and sediment losses from row-crop watersheds, as over 87% and 90% of the runoff events removed more sediment from row-crop watersheds than from the pasture and forest watersheds, respectively. Only 10% of the erosion events were controlled by water quality improvement measures such as minimum tillage, forested riparian buffer strips and grass filter strips on the row-crop watersheds. The grass filter strip on a row-crop watershed effectively reduced NPSP in years with normal precipitation but failed in years with above normal precipitation. This finding indicates that establishment of grass filter strips along streams would reduce sediment loss by approximately 72% in years with normal precipitation. Increasing the width beyond 3-4 m may reduce sediment loss from infrequent large runoff events. An evaluation of erosion from CRP/pasture watersheds indicates that approximately 55% pasture cover within each row-crop watershed would lower the sediment loss by 55%, especially when runoff water goes through the pasture area and the forest buffer before it leaves the watershed. Furthermore, these practices are financially attractive to landowners and farmers because the Conservation Reserve Program subsidizes lost income for agricultural land planted in riparian and CRP/pasture. These practices would also reduce sediment discharges significantly from agricultural watersheds within the Long Branch Watershed and thereby reduce siltation of the lake and the associated cleaning costs while providing other invaluable environmental benefits.

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